OTEC 2018

Pervious Pavement – Lessons Learned During Construction

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Hassan Zahran, PE (CTL)
Erosion Control?
Notes:
1. Construction along Dominion Boulevard between Shields Place and Sellers Avenue shall be phased using City of Columbus STD DWG 1540 sheets 7, 8 & 9.
2. All construction on Dominion shall be completed within 180 days of the start of construction.
3. Road closures that result in the inability for residents to have vehicular access to their driveways shall be limited to 3 weeks at a time for a maximum of 12 driveways when on-street parking is not available in front of their home or an immediately adjacent home.
4. Vehicular access to residential driveways must be maintained from November 23, 2017 through March 17, 2018.
5. It shall be the Contractors responsibility to maintain access to all properties within the project limits at all times. When vehicular access is restricted due to construction activities, an ADA accessible pedestrian access route shall be provided. Where permanent walk is not planned, temporary walk shall be provided by the Contractor. All temporary pedestrian access shall conform to the requirements of City of Columbus Item 608 Temporary Asphalt Concrete Walk, As Per Plan, see sheet 15. Installation of temporary walk, removal of temporary walk and restoration of disturbed areas shall be be paid for under Item 614 Maintain Traffic As Per Plan.
6. Work hours shall comply with City of Columbus Noise Ordinance 0544–03.
7. Contractor employee parking shall not be within 300–feet of the nearest closed driveway.
Contractor didn’t want to spend money on utility backfill that would be removed later.
Tailings had to be brought in to maintain drivable surface.
Weather

- No work that impacts vehicular driveway access between Thanksgiving and Easter
- Wet subgrade, use of stronger fabric allows project to keep moving
Construction Sequencing Suggestions

• Do as much utility work as you can before closing road
• If going with phased construction, don’t let contractor mill off all phases at one time
• Try to find streets with alley access for residents
• Don’t close road during colder months
Subgrade Compaction & Proof Roll
GeoFabric Layers
• Bottom and sides of trench
GeoFabrics

Tencate Mirafi RS-380i
- Reinforcement in weak soils
- High Infiltration Rate

<table>
<thead>
<tr>
<th>Fabric</th>
<th>Permitivity</th>
<th>Grab Strength</th>
<th>Tear/Tensile Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>ODOT Type D</td>
<td>0.05 sec⁻¹</td>
<td>800 N</td>
<td>70 lbs</td>
</tr>
<tr>
<td>Mirafi RS-380i</td>
<td>0.9 sec⁻¹</td>
<td>1500 N</td>
<td>180 lbs</td>
</tr>
</tbody>
</table>
Outlets & Underdrains

All Proposed Perforated Underdrain (PUD) shall be per ASTM F758 PVC SDR 26 with 4 holes, 3/8" perforations, every 3" at 90° and 160°, holes to be facing down.

Stormtech DC-780
Easton video

https://youtu.be/2Kbk6-47WVo
LA Abrasion Test

- The standard LA abrasion test subjects a coarse aggregate sample to abrasion, impact, and grinding in a rotating steel drum containing a specified number of steel spheres.
- LA abrasion of 40 means 40% of the original sample passed through the No. 12 sieve (1.70 mm).
No. 2, 3, or 4 Stone

- Testing Requirements
  - LA Abrasion Test <40 as per ASTM C-131
  - Angular particles >90% (no rounded river gravel)
  - Less than 2% passing No. 200 sieve
  - CBR >80%

- Recycled Concrete Typically Can’t pass the LA abrasion test
Tech South
-Soft rock or contaminated material?
No. 57 Stone

• Testing Requirements
  • LA Abrasion <40
  • Angular particles >90% (no rounded river gravel)
  • Less than 2% passing No. 200 sieve
  • CBR >80%
GeoWeb – Increases Strength

Doubles Layer Coefficient of the Stone Layer it Confines

The GEOWEB® Cell Dimensions

<table>
<thead>
<tr>
<th>Relative Size¹</th>
<th>GW20V</th>
<th>GW30V</th>
<th>GW40V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>GW20V (small cell)</td>
<td>GW30V (mid cell)</td>
<td>GW40V (large cell)</td>
</tr>
<tr>
<td>Nominal Length x Width¹</td>
<td>6.8 x 10.2 in (224 x 259 mm)</td>
<td>11.3 x 12.6 in (287 x 320 mm)</td>
<td>10.5 x 13.0 in (267 x 330 mm)</td>
</tr>
<tr>
<td>Nominal Area²</td>
<td>44.8 in² (289 cm²)</td>
<td>71.3 in² (460 cm²)</td>
<td>66.3 in² (440 cm²)</td>
</tr>
<tr>
<td>Cells per yd³</td>
<td>28.9 (34.6)</td>
<td>18.2 (21.7)</td>
<td>N/A</td>
</tr>
<tr>
<td>Nominal Depths</td>
<td>3 in (76 mm), 4 in (100 mm), 6 in (150 mm), and 8 in (200 mm) for all cells</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹ All details and dimensions are nominal and subject to manufacturing tolerances.
² Cell area will vary approximately ± 5% through the recommended expansion range.

No. 8 Setting Bed

- Testing requirements
  - LA Abrasion Test <40 as per ASTM C-131
  - Angular particles >90% (no rounded river gravel)
  - Less than 2% passing No. 200 sieve
  - CBR >80%
Compaction Equipment

10-12 Ton Roller
Compaction of Stone Layers

• Roll (2) Vibratory Mode
• Roll (2) Static Mode
• Test w/Light Weight Deflectometer
  • 1.0 mm for No. 2, 3, or 4 stone
  • 0.5 or less for No. 57 stone
• Fail Test, re-roll until it passes
• Cannot test for density
Deflectometer Testing

Procedure
1. (3) Drops to Seat plate
2. (3) More Drops record readings
3. Take average of last (3) readings

<table>
<thead>
<tr>
<th>Material</th>
<th>Maximum Deflection</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 2, 3, or 4 Stone</td>
<td>1 mm</td>
</tr>
<tr>
<td>No. 57 Stone</td>
<td>0.5 mm</td>
</tr>
</tbody>
</table>

Note
1. First lift of base stone may have high readings because the native subgrade will deflect and elevate the readings
2. Can only test to a depth equal to plate diameter = 12”
Light Weight Deflectometer

- Purchased by CTL
  - $6000
- Easy to use
- Good form of QA/QC between contractor and inspector
- Most tests passed, few small areas had to be re-rolled
Poor Stone Compaction
Lift Thickness

• 12” or less

09/24/2013
Poor Stone Compaction?
Poor Stone Compaction
1. Obtain Subgrade CBR value (typically 2-7)
2. Calculate Traffic Load
3. Calculate Structural Number
4. Design Subbase Stone Thickness Based on Layer Coefficients

City of Columbus No credit for:
- Geoweb
- Geogrid
- Geofabrics
### Traffic Loads – Maximum 1,000,000 ESAL’s

**Table 3-1. Road Classification, Description and Traffic (after BIA 2003)**

<table>
<thead>
<tr>
<th>Road Class</th>
<th>Description</th>
<th>Design ESALs*</th>
<th>Design TI**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial</td>
<td>Through traffic with access to high-density, regional, commercial and office developments or downtown streets. General traffic mix.</td>
<td>9,000,000</td>
<td>11.5</td>
</tr>
<tr>
<td>Major Collector</td>
<td>Traffic with access to low-density, local, commercial and office development or high density, residential sub-divisions. General traffic mix.</td>
<td>3,000,000</td>
<td>10</td>
</tr>
<tr>
<td>Minor Collector</td>
<td>Through traffic with access to low-density, neighborhood, commercial development or low-density, residential sub-divisions. General traffic mix.</td>
<td>1,000,000</td>
<td>9</td>
</tr>
<tr>
<td>Bus Passenger Drop-off</td>
<td>Public transport centralized facility for buses to pick up passengers from other modes of transport, or for parking of city or school buses.</td>
<td>500,000</td>
<td>8.5</td>
</tr>
<tr>
<td>Local Commercial</td>
<td>Commercial and limited through traffic with access to commercial premises and multi-family and single-family residential roads. Used by automobiles, service vehicles and heavy delivery trucks. This category includes large parking lots at commercial retail facilities.</td>
<td>330,000</td>
<td>8</td>
</tr>
<tr>
<td>Residential</td>
<td>No through traffic with access to multi-family and single-family residential properties. Used by automobiles, service vehicles and light delivery trucks, including limited construction traffic.</td>
<td>110,000</td>
<td>7</td>
</tr>
<tr>
<td>Facility Parking and Alleys</td>
<td>Parking areas for automobiles at large facilities with access for emergency vehicles and occasional use by service vehicles or heavy delivery trucks.</td>
<td>90,000</td>
<td>7</td>
</tr>
<tr>
<td>Commercial Parking</td>
<td>Restricted parking and drop-off areas associated with business premises, mostly used by automobiles and occasional light delivery trucks. No construction traffic over finished surfaces.</td>
<td>30,000</td>
<td>6</td>
</tr>
<tr>
<td>Commercial Plaza</td>
<td>Predominantly pedestrian traffic, but with access for occasional heavy maintenance and emergency vehicles. No construction traffic over finished surfaces.</td>
<td>10,000</td>
<td>5</td>
</tr>
</tbody>
</table>

*ESAL = 18,000 lb (80 kN) equivalent single axle load

**TI = Caltrans Traffic Index TI = 9 X (ESALs/1,000,000) weighing

***Consult a pavement engineer
Columbus Residential Design Policy

Typical short one to two block long loop street with no future extensions

- 1,500 cars/day
- 5% trucks
- 30 Year Design Life
- Directional Distribution = 50%
- Design Lane Distribution Factor = 100%
- B/C Ratio – Other Urban (Use 0.725)

Total ESALs: 299,962
CBR = 3.0  
Total Flexible ESALs = 299,962  
Resulting Structural No. = 3.55

<table>
<thead>
<tr>
<th>Material</th>
<th>Layer Coefficient</th>
<th>Thickness (in)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 2, 3, or 4 Stone</td>
<td>0.06</td>
<td>30</td>
<td>1.80</td>
</tr>
<tr>
<td>No. 57 Stone</td>
<td>0.09</td>
<td>4</td>
<td>0.36</td>
</tr>
<tr>
<td>Pavers &amp; Setting Bed</td>
<td>0.30</td>
<td>4.625</td>
<td>1.39</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>Total</strong></td>
<td>3.55</td>
</tr>
</tbody>
</table>
Structural Thickness Design No. 2

CBR = 5.0
Total Flexible ESALs = 299,962
Resulting Structural No. = 2.95

<table>
<thead>
<tr>
<th>Material</th>
<th>Layer Coefficient</th>
<th>Thickness (in)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 2, 3, or 4 Stone</td>
<td>0.06</td>
<td>20</td>
<td>1.39</td>
</tr>
<tr>
<td>No. 57 Stone</td>
<td>0.09</td>
<td>4</td>
<td>0.36</td>
</tr>
<tr>
<td>Pavers &amp; Setting Bed</td>
<td>0.30</td>
<td>4.625</td>
<td>1.39</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>2.95</strong></td>
</tr>
</tbody>
</table>
### UC Davis Design Tables

**MPa = 17.61 x CBR^{0.64}**  
(CBR of 3 = MPa 36)

#### Annual Number of Days with Rainfall (46 years of record)

<table>
<thead>
<tr>
<th>Rainfall (in)</th>
<th>Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1”</td>
<td>71</td>
</tr>
<tr>
<td>0.25”</td>
<td>44</td>
</tr>
<tr>
<td>0.5”</td>
<td>24</td>
</tr>
<tr>
<td>1”</td>
<td>9</td>
</tr>
<tr>
<td>1.5”</td>
<td>3</td>
</tr>
<tr>
<td>2”</td>
<td>2</td>
</tr>
</tbody>
</table>

#### Table 9.1: Design Table for PICP (Metric) (continued)

<table>
<thead>
<tr>
<th>Number of Days in a Year When the Subbase has Standing Water (Wet Days)</th>
<th>50</th>
<th>90</th>
<th>120</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resilient Modulus of Subgrade (MPa)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry</td>
<td>40</td>
<td>60</td>
<td>80</td>
</tr>
<tr>
<td>Wet</td>
<td>24</td>
<td>36</td>
<td>48</td>
</tr>
<tr>
<td>Cohesion (kPa), Internal Friction Angle of Subgrade (°)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry</td>
<td>10</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>Wet</td>
<td>6</td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td>Lifetime ESALs (Traffic Index)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50,000 (6.3)</td>
<td>175</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>100,000 (6.8)</td>
<td>285</td>
<td>180</td>
<td>150</td>
</tr>
<tr>
<td>200,000 (7.4)</td>
<td>395</td>
<td>285</td>
<td>185</td>
</tr>
<tr>
<td>300,000 (7.8)</td>
<td>455</td>
<td>340</td>
<td>240</td>
</tr>
<tr>
<td>400,000 (8.1)</td>
<td>500</td>
<td>380</td>
<td>280</td>
</tr>
<tr>
<td>500,000 (8.3)</td>
<td>530</td>
<td>410</td>
<td>305</td>
</tr>
<tr>
<td>600,000 (8.5)</td>
<td>555</td>
<td>435</td>
<td>330</td>
</tr>
<tr>
<td>700,000 (8.6)</td>
<td>580</td>
<td>455</td>
<td>350</td>
</tr>
<tr>
<td>800,000 (8.8)</td>
<td>600</td>
<td>470</td>
<td>365</td>
</tr>
<tr>
<td>900,000 (8.9)</td>
<td>615</td>
<td>485</td>
<td>380</td>
</tr>
<tr>
<td>1,000,000 (9.0)</td>
<td>630</td>
<td>500</td>
<td>390</td>
</tr>
</tbody>
</table>

1. Default values based on testing cited in the literature (10,12)
CBR = 3.0 (soaked)
MPa = 36
ESALs = 300,000
No. of Days with Wet Subgrade = 71 (use 90)
No. 2 Stone Layer Thickness = 375 mm = 15"
Total Thickness = 15” + 4” + 3 1/8” = 22 1/8”
Site Stabilization
• Use Sod
• No grass seed
Concrete bands

- 18”x6” straight curb
- 12”x12” flush band
Concrete Pavers – Unilock EnduraColor

EnduraColor

Traditional

facemix
Third Street New Albany
Pine Hall Brick – Iron Spot (2 ¾”)
## Paver Material & Install Prices

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unilock Endura Color</td>
<td>$4.50/SF delivered</td>
</tr>
<tr>
<td>Unilock Standard Color</td>
<td>$2.60/SF delivered</td>
</tr>
<tr>
<td>Pine Hall Clay:</td>
<td>$4.50/SF delivered</td>
</tr>
<tr>
<td>Machine Install Price</td>
<td>$2.00/SF (includes setting bed &amp; chips)</td>
</tr>
<tr>
<td>Hand Install Price</td>
<td>$5.00/SF (includes setting bed &amp; chips)</td>
</tr>
</tbody>
</table>
Clay Paver Parking Stall Installation

To Small of an area for machine installation, use hand setting prices.
<table>
<thead>
<tr>
<th>Item No.</th>
<th>Description</th>
<th>Total</th>
<th>Unit</th>
<th>Low Bid</th>
<th>Total Cost</th>
<th>Contractor Suggested Change</th>
<th>New Bid Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>203</td>
<td>EXCAVATION</td>
<td>11,411</td>
<td>CY</td>
<td>$20.00</td>
<td>$228,220.00</td>
<td>$5.00</td>
<td>$25.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>605</td>
<td>6&quot; PVC PIPE UNDERDRAIN PERFORATED, AS PER PLAN</td>
<td>2925</td>
<td>LF</td>
<td>$15.00</td>
<td>$43,875.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>660</td>
<td>SODDING, UNSTAKED</td>
<td>1,912</td>
<td>SY</td>
<td>$12.00</td>
<td>$22,944.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPEC</td>
<td>PRESTO GEOWEB GW20V (3-inch), OR EQUAL</td>
<td>7,888</td>
<td>SY</td>
<td>$8.00</td>
<td>$63,104.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPEC</td>
<td>PERVIOUS CONCRETE PAVERS (T=3 1/8&quot;)</td>
<td>70,794</td>
<td>SF</td>
<td>$7.50</td>
<td>$530,955.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPEC</td>
<td>AGGREGATE BASE, AS PER PLAN NO. 57 STONE (T=4&quot;)</td>
<td>1,033</td>
<td>CY</td>
<td>$51.00</td>
<td>$52,683.00</td>
<td>$5.00</td>
<td>$56.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPEC</td>
<td>AGGREGATE BASE, AS PER PLAN (NO. 2, 3, OR 4 STONE)</td>
<td>9,529</td>
<td>CY</td>
<td>$39.00</td>
<td>$371,631.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPEC</td>
<td>WOVEN GEOSYNTHETIC Mifafi RS380i or EQUIVALENT</td>
<td>9,801</td>
<td>SY</td>
<td>$5.30</td>
<td>$51,945.30</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **203**: Hard to work in existing streets.
- **605**: More work to get to grade than anticipated.
## Bid Prices (70,794 SF pervious pavement)

<table>
<thead>
<tr>
<th>Contractor</th>
<th>Bid</th>
</tr>
</thead>
<tbody>
<tr>
<td>George Igel</td>
<td>$3.6 million</td>
</tr>
<tr>
<td>Shelly &amp; Sands</td>
<td>$3.8 million</td>
</tr>
<tr>
<td>Conie Construction</td>
<td>$4.1 million</td>
</tr>
<tr>
<td>Facemeyer</td>
<td>$4.2 million</td>
</tr>
<tr>
<td><strong>Estimate</strong></td>
<td><strong>$4.6 million</strong></td>
</tr>
</tbody>
</table>

**Includes**

- 20% Force Account
- $405,000 street sweeper
- $129,000 contingency items

**Cost Per SF**

Low bid (w/o force account, contingency, and sweeper) = $34.60/SF
Paver Installation Contractor

• Most Knowledgeable

• Minimum Responsibilities
  • No. 8 Setting Bed
  • Set Pavers
  • Sweep in Chips
  • Plate Compact Finished Pavers
  • Replace Cracked or Chipped Bricks
  • Re-joint with Aggregate as needed until end of 2-year Warranty Period

• Laying patterns
  • Soldier Course
  • Herringbone
  • Stagger lines
  • Swap pavers
  • Special Patterns
Paving contractor

- Screed machine
  - Much slower if done by hand
- Saw cutting is very loud
- Pavers will look dirty for awhile with all the concrete dust & chip dust
Plate Compactor

• Use in areas not reachable by roller
• Minimum Force of 13,500 lbf for Stone
• Minimum Force of 5,000 lbf for Pavers
Swap ½ Pieces to Break Up Lines
Provide Laying Details Around Catch Basins and Manholes – Low Volume Streets
Provide Laying Details Around Catch Basins and Manholes – Higher Volume Streets
Warranty and As-Built Tolerances

**Warranty Covers**
- Creep
- Cracked pavers
- Loss of Joint material

**Warranty Does not Cover**
- Sediment removal

**As-built Tolerances**
- Final elevations not deviate more than 3/8” over 10-feet
- Lippage shall be no greater than 1/8” between pavers
- Bond lines shall be +/-1/2” over a 50-ft string line
- Top of pavers may be 1/8” to ¼” above adjacent structures for possible minor settling
Construction Observations

• General contractor
  • Doesn’t like to roll stone
  • Doesn’t like shallow lift depths
  • Doesn’t like sod
  • Doesn’t like multiple mobilizations for pavement planning
  • Doesn’t like to use plate compactor to compact stone at edges
  • Doesn’t like phased construction
    • Tree removal
    • Curb
    • Only wants subcontractors there once

• General contractor is typically least knowledgeable of the bunch
• Paver Installer is most knowledgeable
• Inspectors have never seen a project like this before
  • Deflectometer helps them quantify inspection
Design Engineer

- Construction Observation Contract with City
- Answered a lot of Questions in Field
  - Contractor
  - Inspector
  - Residents
- Light Weight Deflectometer Training
- Attended Monthly Project Meetings
References

• City of Columbus
  • Supplement Spec 1525 – Permeable Pavement
  • Standard Details
    • Typical Section
    • Concrete Band Detail
    • Castings Detail
    • Laying Patterns
  • Green Infrastructure Design Manual Update
East Dominion Before
East Dominion After
QUESTIONS?